The Role of Thermochemical Technologies in Advanced Biorefineries

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North Central Region Feedstock Workshop
Sioux Falls, SD
August 15, 2006

Biorefinery

"A processing and conversion facility that (1) efficiently separates its biomass raw material *into individual components* and (2) converts these components into marketplace products, including biofuels, biopower, and conventional and new bioproducts."

The Biomass Research and Development
Technical Advisory Committee (2002)
U.S. Departments of Energy and Agriculture

Approaches to Biorefineries

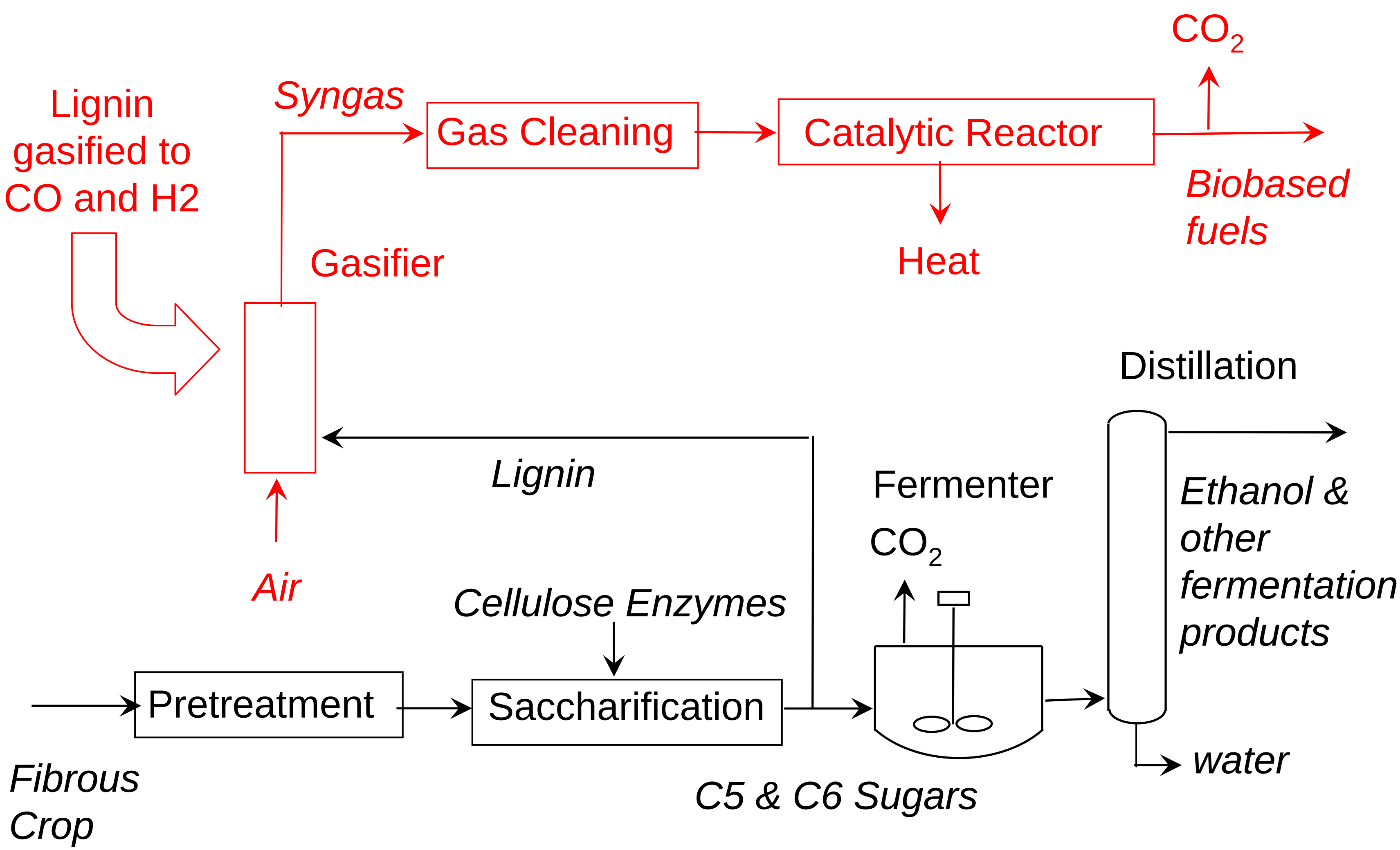
- Biochemical (sugar platform)
- Thermochemical
  - Gasification
  - Fast pyrolysis
- Hybrid thermochemical/biochemical
  - Syngas fermentation
  - Bio-oil fermentation

Ethanol and Biodiesel are not the Only Possible Biobased Fuels

Fuel	Specific Gravity	LHV (MJ/kg)	Octane Number	Cetane Number
Ethanol	**0.794**	**27**	**109**	**-**
Biodiesel	**0.886**	**37**	**-**	**55**
Methanol	0.796	20.1	109	-
Butanol	0.81	36	96 - 105	-
Fischer-Tropsch Diesel	0.770	43.9	-	74.6
Hydrogen	0.07 (liq)	120	>130	-
Methane	0.42 (liq)	49.5	>120	-
Ammonia	0.68 (liq)	18.8	110	-
Dimethyl Ether	0.66 (liq)	28.9	-	>55
Gasoline	0.72-0.78	43.5	91-100	-
Diesel	0.85	45	-	37-56

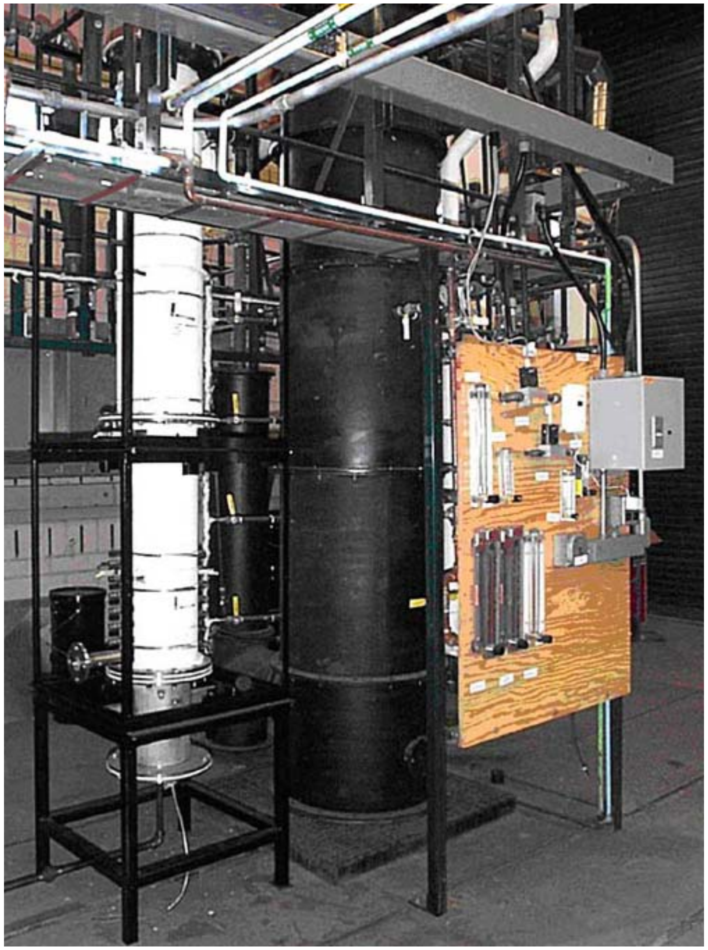
Biochemical Biorefinery

(with thermochemical boost)



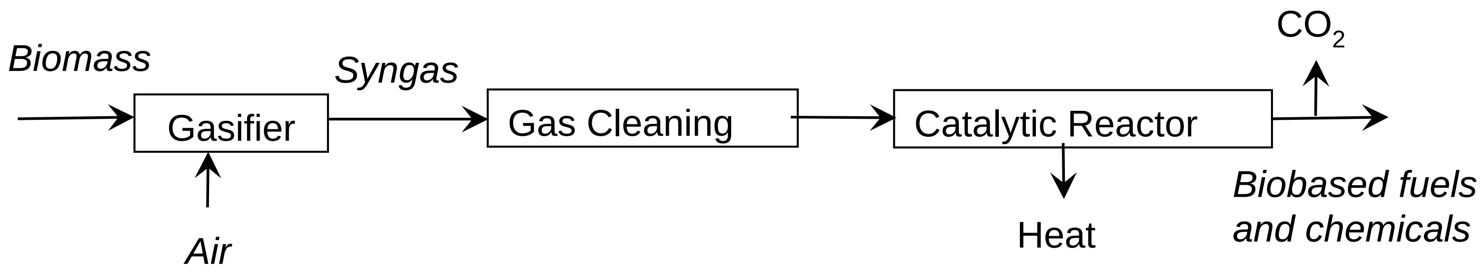
Gasification Biorefinery

- Fibrous or mixed feedstock heated in absence of oxygen to yield mixture of CO and H_2 (syngas) and char byproduct
- Gas clean-up followed by high pressure catalytic synthesis to products
  - Alcohols
  - Hydrocarbons



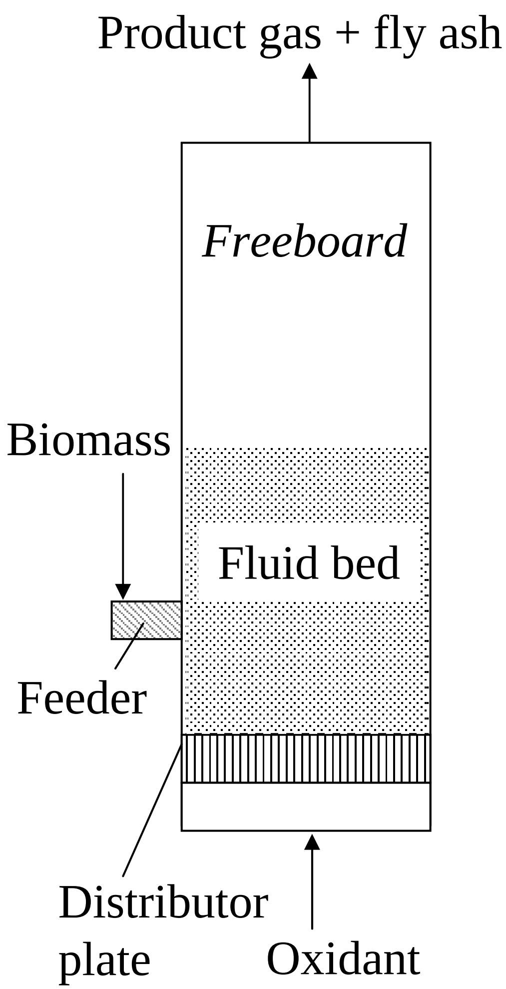
Gasification Biorefinery

- Advantages (compared to biochemical platform)
  - Tolerates relatively dirty biomass feedstock
  - Produces uniform intermediate product (syngas)
  - Proven method for “cracking the lignocellulosic nut”
  - Allows energy integration in biorefinery
- Disadvantages (compared to biochemical platform)
  - Gas cleaning technologies still under development
  - Synfuel processing occurs at high pressures
  - Capital costs thought to be higher

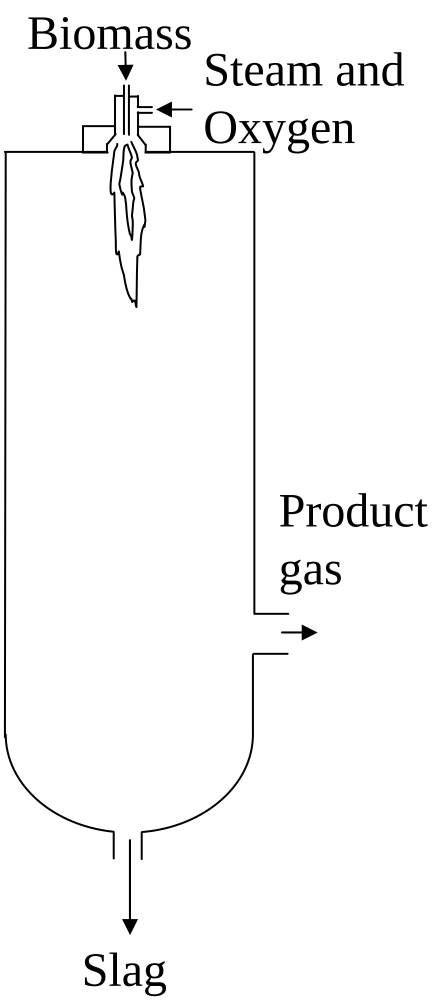


Candidate Gasifiers

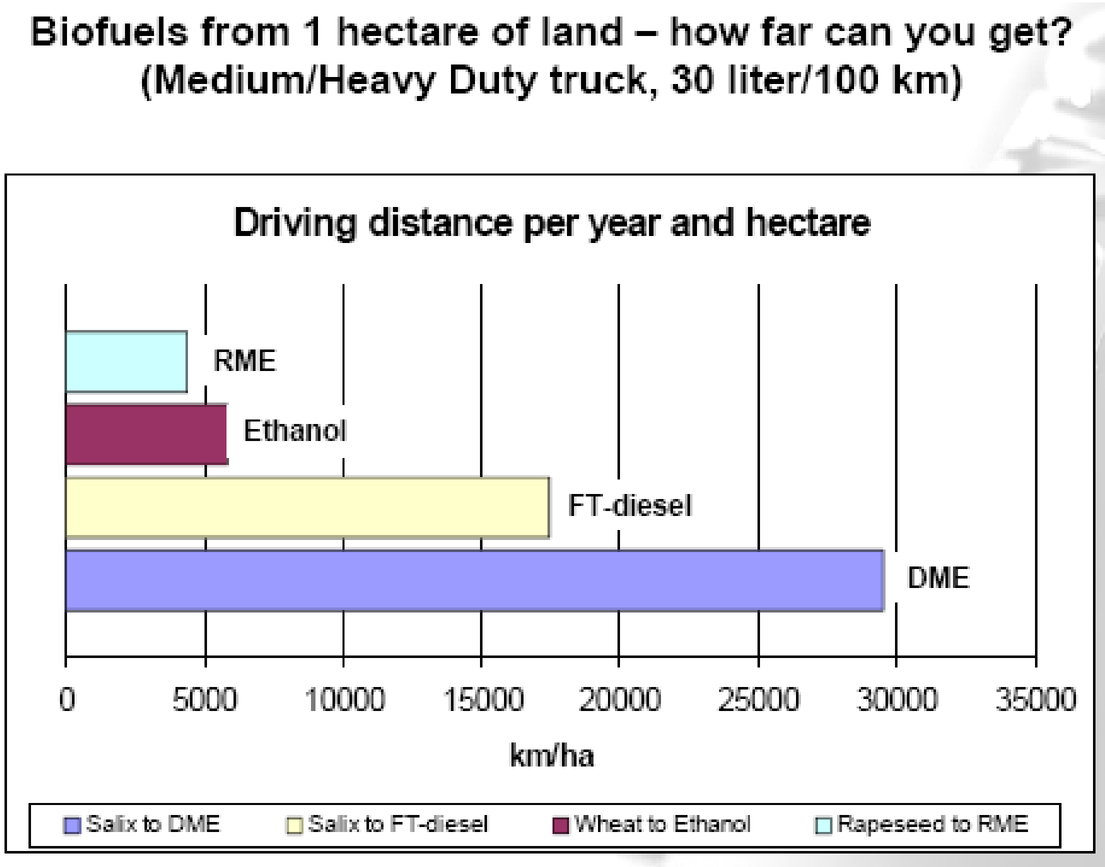
Fluidized Bed



Entrained Flow



Synfuels Yield Advantage

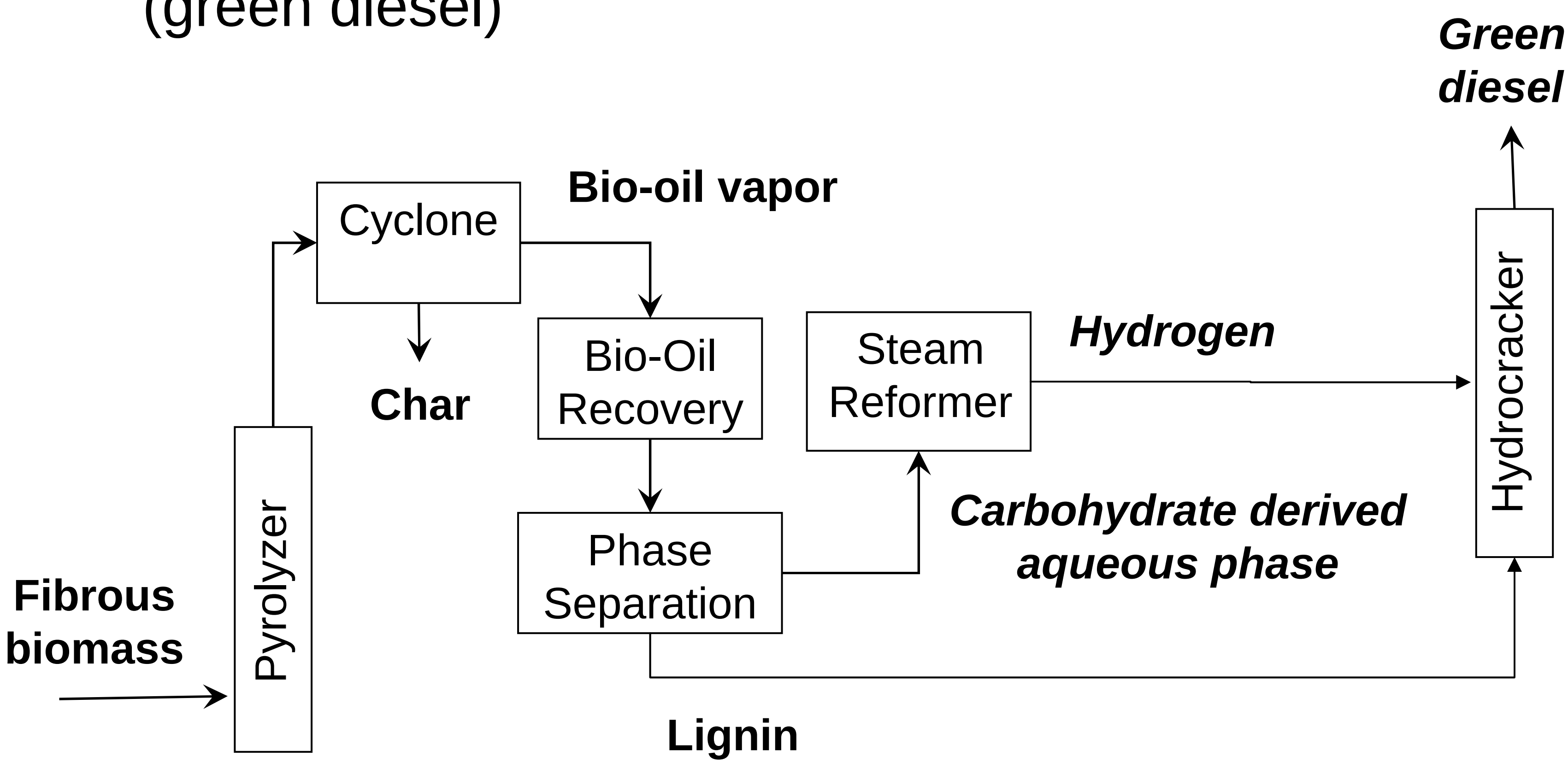


Source: Röj, A.*, Automotive Fuels from Biomass – What is the best road forward, First International Biorefinery Workshop, Washington, D.C., July 20-21, 2005, http://www.biorefineryworkshop.com/presentations/Roj.pdf

* Volvo Technology Corporation, anders.roj@volvo.com

Fast Pyrolysis Biorefinery

- Directly converts biomass into liquid bio-oil (lignin, carbohydrate derivatives, and water) and char
- Bio-oil catalytically converted into hydrocarbon fuel (green diesel)

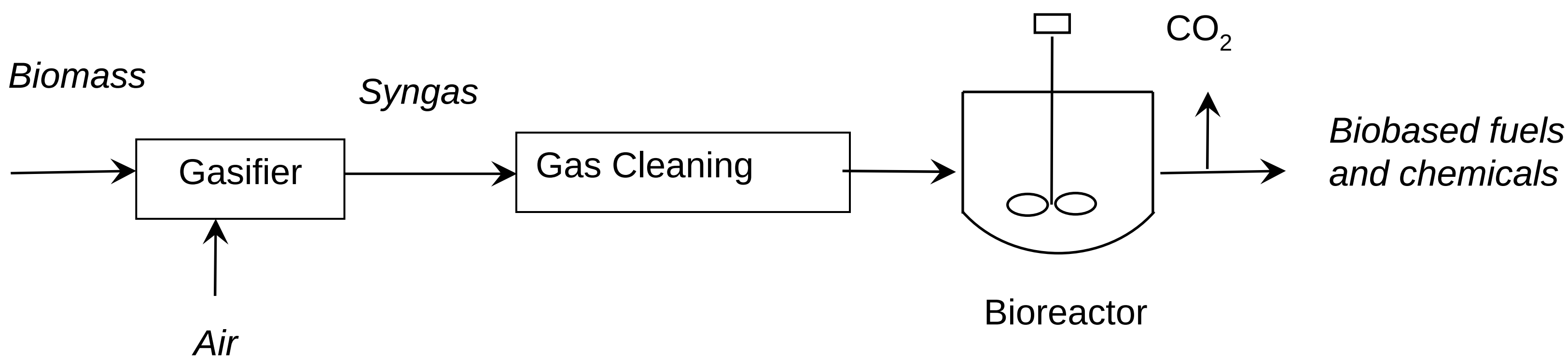


Fast Pyrolysis Biorefinery

- Advantages (compared to biochemical platform)
  - Opportunity for distributed preprocessing (densifies biomass)
  - Separates and uses both carbohydrate and lignin
  - Integrates into existing petroleum refineries
- Disadvantages (compared to biochemical platform)
  - Bio-oil can be unstable, corrosive
  - Technology less developed

Syngas Fermentation

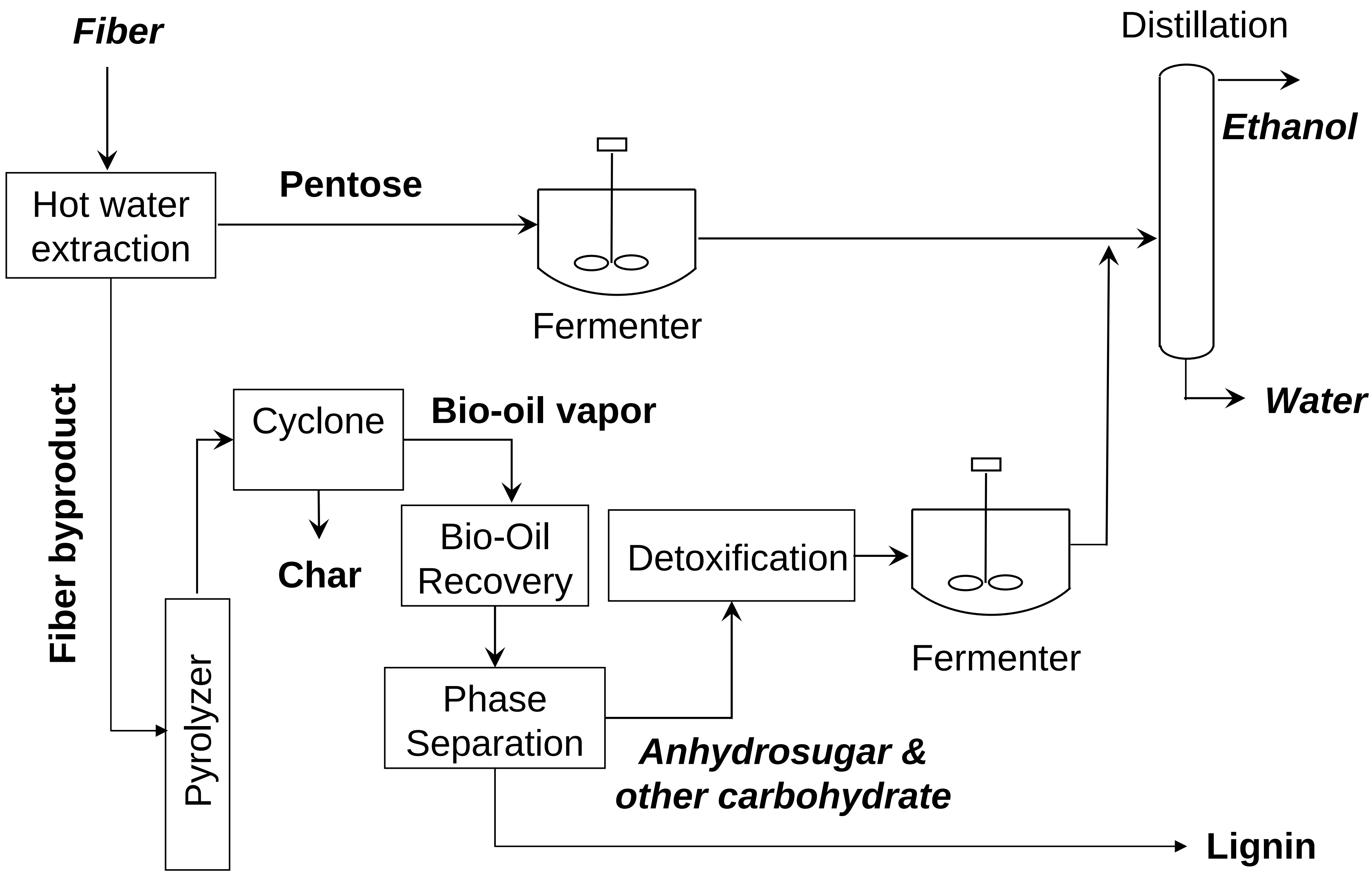
- Biomass gasified to CO, CO_2 and H_2
- Autotrophic organisms ferment CO or CO_2 and H_2 into metabolic products
  - Alcohols, carboxylic acids, esters



Syngas Fermentation Biorefinery

- Advantages (compared to gasification biorefinery)
  - Biocatalysts tolerant to sulfur and chlorine contaminants
  - Flexibility in the pressures and CO/H_2 ratios employed
  - High selectivity in products produced
  - Genetic engineering can expand portfolio of products
- Disadvantages (compared to gasification biorefinery)
  - Low rates of gas-liquid exchange
  - Less developed technology

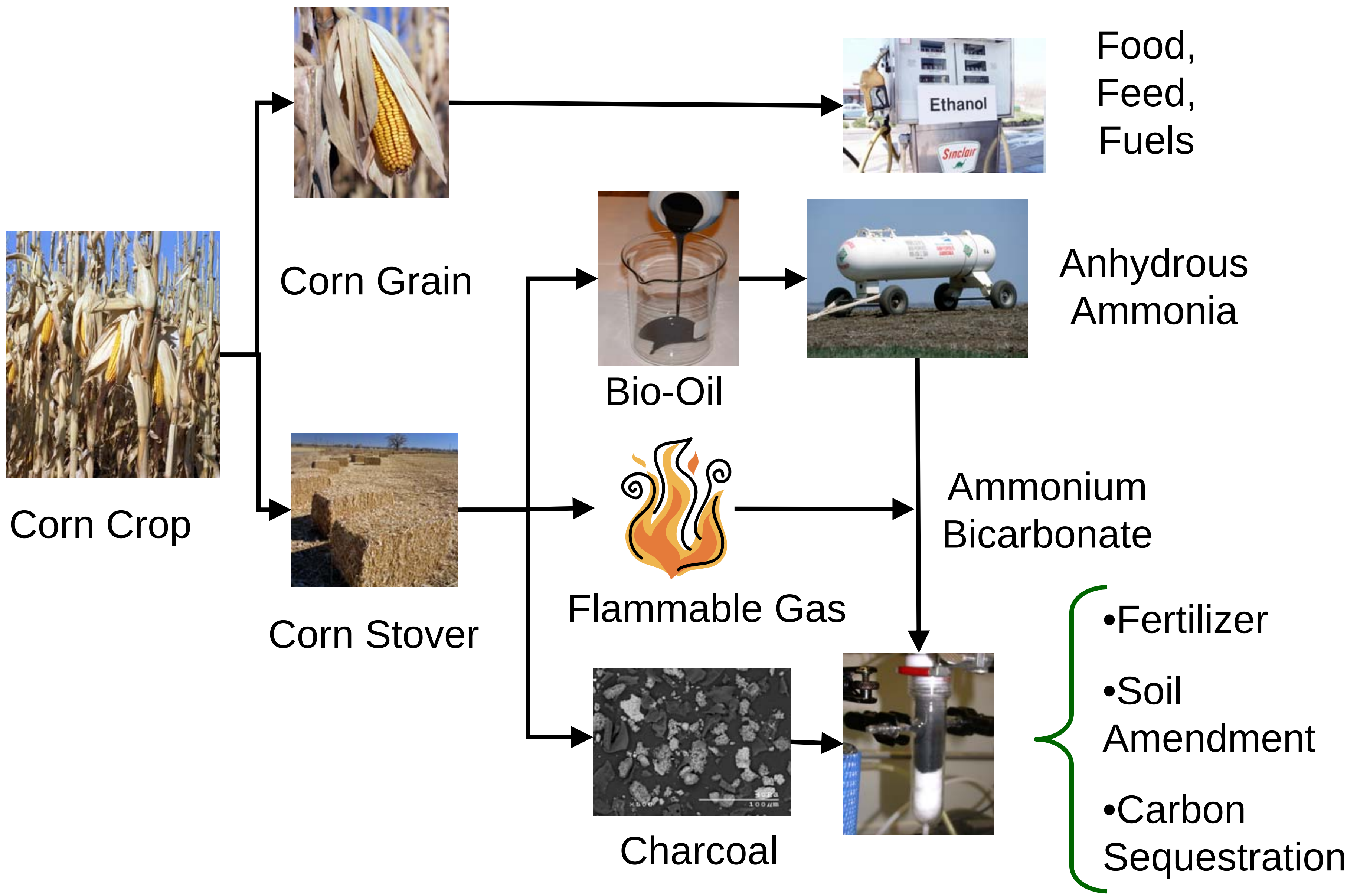
Bio-Oil Fermentation Biorefinery



Bio-Oil Fermentation Biorefinery

- Advantages (compared to biochemical)
  - Opportunity for distributed preprocessing
  - Avoids enzymatic hydrolysis bottleneck
- Advantages (compared to thermochemical)
  - Avoids high pressure operations
  - Opportunities for biotechnology advances (such as direct fermentation of anhydrosugar)
- Disadvantages
  - Bio-oil is complex mixture of compounds
  - Technology not well developed

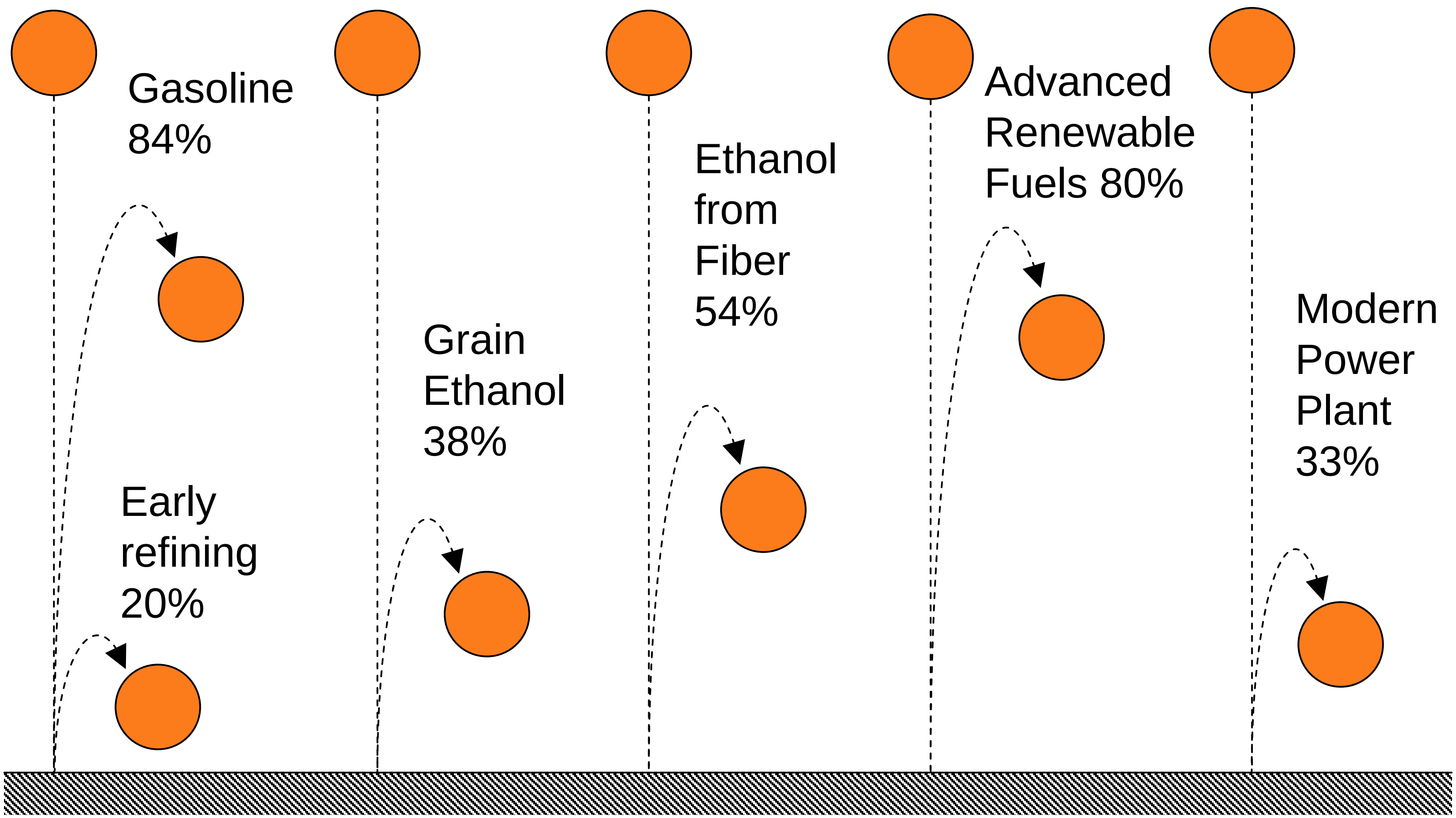
Fiber to Fertilizer Biorefinery



Benefits of Fiber to Fertilizer Biorefinery

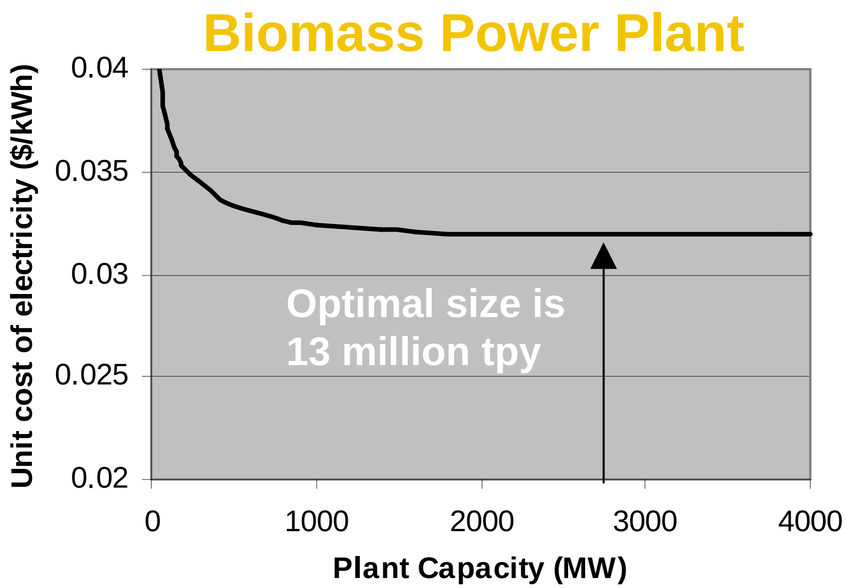
- Fertilizer credit to farmer (\$205/ton NH_3) by providing stover for hydrogen production.
- 620 acre farm sequesters 1900 tons/yr of CO_2 (equivalent to CO_2 emissions from 330 automobiles).
- Carbon credit based on carbon trading in Europe under the Kyoto Accord in late 2005 (\$20/ton of sequestered CO2): additional income of \$30,000 for 620 acre farm.

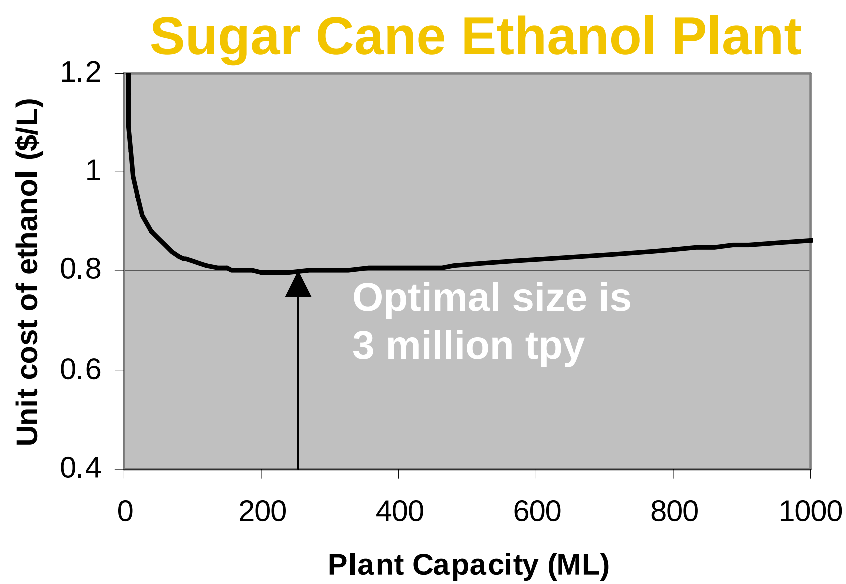
Energy Efficiency of Biofuels Production



Source: RBAEF Project (Lee Lynd, Dartmouth)

Will a Thermochemical Biorefinery Have a Size Disadvantage?





- Optimal size for biomass power plant is much larger than for ethanol plant
- Optimization curves are relatively flat
- Depends upon ratio of biomass transportation cost to processing plant cost (not biomass cost)

Opportunities Start Today

- Grain ethanol production consumes equivalent of 20% of natural gas use in Iowa
  - 3.5% for fertilizer to grow corn
  - 16% for process heat in ethanol plants
- Biomass gasification or fast pyrolysis could provide substitute for natural gas
- Commercialization has already commenced

Feedstock Issues with Thermochemical Refineries

- Transportation: Economics may dictate larger thermochemical refineries than for biochemical refineries
- Feeding: Biomass cannot be slurried with water for feeding into high pressure gasifiers
- Moisture content: Robs thermodynamic efficiency
- Inorganics: Plant nutrients are contaminants in thermochemical processing
  - Ash fouling (alkali)
  - Catalyst poisoning (sulfur and chlorine)

Summary

- Biorefineries based on lignocellulosic biomass will be essential to meeting future renewable fuel demand
- Future renewable fuels not necessarily ethanol
- Several options for lignocellulosic biorefineries
  - Biochemical (sugar platform)
  - Thermochemical
  - Hybrid thermochemical/biological
- Feedstock properties will influence design of thermochemical biorefineries